Politics of pacemaker dominance

Dear Sir:

In a recent article in this journal, Sherman and Rinzel (1991) take issue with our characterization of the interaction among cells of the sinoatrial node as "democratic" (Michaels et al., 1987). They suggest instead that a more accurate term might be "oligarchic." While it is perhaps dangerous to pursue this admittedly anthropomorphic analogy too far, we feel it necessary to justify our choice of the term "democratic."

When we did our simulation studies of pacemaker interactions in the sinus node, we were attempting to define a new way in which coordinated firing of the entire sinus node could be described. The dominant view at that time was that there was a single "master" pacemaker cell that was the fastest and that when it fired all other cells followed suit. On the basis of our previous experimental and modelling work on the interaction between two coupled pacemakers, we hypothesized that the mutual interaction of the thousands of pacemaker cells comprising the compact region of the sinoatrial node was an alternative mechanism for their coordinated activation. To test that hypothesis, we performed the simulations described in our 1987 paper, and our results supported our hypothesis. To distinguish between the prevailing concept of control of all cells by only one (or at most a few) and our new hypothesis of mutual entrainment via equal interaction of all cells, we made use of a political analogy in which we likened control of activity by a single cell to a "dictatorship" and coordination via mutual interaction to a "democracy." Implicitly inherent in our choice of the term democracy was the observation that not all cells were equal in terms of their intrinsic frequency, but that all cells had equal influence on their neighbors.

To illustrate this equality of influence, it is perhaps most instructive to consider the case of only two interacting pacemakers. When not coupled, each pacemaker beats independently at its own intrinsic frequency. Thus, they are, by definition, not equal. However, when they are coupled together through an ohmic resistor, the current flowing from one cell to the other (i.e., the coupling current) is strictly a function of the differences in their voltages. At any given instant the coupling current for one cell is equal and opposite to that for the other. By means of this coupling current, they mutually influence one another. The faster cell does indeed increase the frequency of the slower, but the reverse is also true. The slower cell slows down the faster one. They thus arrive at a mutual consensus. There is not more influence of one cell on the other.

The importance of this equality of influence on the interaction of many pacemakers is illustrated by a simulation reported in our 1987 paper (Fig. 5 of Michaels et al., 1987). For that simulation, we attempted to reproduce the pattern of activation seen experimentally in the rabbit sinoatrial node. The model consisted of an array of 225 cells, most of which had the same intrinsic frequency. There was a single group of 4 cells with a faster intrinsic frequency. When the cells were coupled together and allowed to interact for several beats, a dominant pacemaker emerged. However, it was not at the site of the intrinsically fastest cells, but shifted to left. And the frequency of the intrinsically fastest cells was reduced. This conclusively demonstrates that there is equality of influence.

We chose to term this consensus by equality of influence a "democracy" specifically to distinguish it from the scheme by which one cell would "force" all the others to fire. However, the use of analogies can be misleading, and one can become mired in irritating differences between the two objects being compared. This is "like" a democracy in several ways: the individuals are inherently different, there is a mechanism for polling them to determine what they want to do, there is equality of influence (one on another), and the final decision reached is a consensus based on this equality of influence. However, the sinus node is not a society and cells are not persons in that society. It is also true that other individuals might have definitions of democracy that differ more or less from that we assumed when making the analogy.

The crux of our objection to the suggestion by Sherman and Rinzel that the system is oligarchic is their further clarification that they assume this because some cells are "more equal than others." That can only be true if there is inequality of influence. In our case there was not. So whether one wishes to term the interaction a democracy or an oligarchy or an aristocracy or even a theocracy is irrelevant, so long as one recognizes that there is, at least in our model system, true equality of influence. This equality is implicit in the equations that describe the dynamics of the system. Indeed, if this essential point is recognized, then the political frame of reference used for developing the analogy is immaterial.

REFERENCES

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Donald C. Michaels and Jose Jalife

Department of Pharmacology
College of Medicine
Health Science Center
State University of New York
Syracuse, New York 13210

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